Cherenkov Telescope Array
Status And Outlook

Stefan Schlenstedt
Oct 30, 2015
Gamma-Ray Astronomy
The Pioneering Experiment

> WHIPPLE
> Start 1968
> Crab in 1986
> Stopped 2011
upper atmosphere
upper atmosphere

Cherenkov light
Measurement Principle

Cherenkov light

- 0.7...2.5 m camera
- nsec pulses
- 6-32 m focal length
- F/D 1...1.5
- 0.4...1.5 m mirrors

Not to scale
Measurement Principle

Cherenkov light

0.7...2.5 m camera
nsec pulses

6-32 m focal length
F/D 1...1.5

0.4...1.5 m mirrors

not to scale

intensity → energy
orientation → direction
shape → primary particle
stereo → source position
Modern Gamma-Ray Instruments

VERITAS

MAGIC

H.E.S.S.
Modern Gamma-Ray Instruments

- MAGIC
- VERITAS
- H.E.S.S.
- 4x12m
- 2x17m
- 4x12m + 1x28m
Modern Gamma-Ray Instruments

- FERMI
- VERITAS
- MAGIC
- H.E.S.S.
- 4x12m
- 2x17m
- 4x12m + 1x28m
Gamma-Ray Sources

Source Types
- PWN
- XRB PSR Gamma BIN
- HBL IBL FRI FSRQ LBL AGN (unknown type)
- Shell SNR/Molec. Cloud
- Starburst
- DARK UNID Other
- uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN WR

1989-1999
Gamma-Ray Sources

1989-1999

today

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with FERMI
Gamma-Ray Sources

1989-1999

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Kifune Plot

Number of sources

10^4
10^3
10^2
10^1
10

1960 1980 2000 2020

year

γ-rays

FERMI

Hess II

MAGIC II

VHE γ-rays

HEGRA

Whipple

SAS-2

COS B

EGRET

Tenma

Ginga

Asca

Uhuru

X-rays

with FERMI
Gamma-Ray Sources

1989-1999

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Kifune Plot

Number of sources

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Today with FERMI
The Next Generation: Cherenkov Telescope Array

- Ten times higher sensitivity
- Extended energy range
- Improved angular resolution
- Observatory – on both hemispheres
Explore Extreme Cosmic Accelerators

- High energy astronomy is the study of astronomical objects that release electromagnetic radiation of highly energetic wavelengths. It includes X-ray astronomy, gamma-ray astronomy, and extreme UV astronomy, as well as studies of neutrinos and cosmic rays. [Wikipedia]

- Astronomy, astro-physics and astro-particle physics

- Investigate the high-energy universe:
  - Acceleration, propagation and radiation of ultra-relativistic protons/ nuclei and electrons
  - Extreme environments: huge fields, high temperatures, shock waves
  - Association with relativistic outbursts, in particle jets in the environments of black holes (AGN, micro quasars, GRB) and in cold ultra-relativistic pulsar winds
Sources of cosmic rays

Astrophysics of sources

Acceleration

Particle propagation

Supernova Remnants

Gamma Ray Bursts

Micro quasars

Active Galactic Nuclei

Pulsar (Wind Nebula)

Starburst galaxies

Dark Matter

Unknown sources
## Mapping of Science Themes to Key Science Projects

<table>
<thead>
<tr>
<th>Theme</th>
<th>Question</th>
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| **1 Understanding the Origin and Role of Relativistic Cosmic Particles** | 1.1 What are the sites of high-energy particle acceleration in the universe?  
1.2 What are the mechanisms for cosmic particle acceleration?  
1.3 What role do accelerated particles play in feedback on star formation and galaxy evolution? |
| **2 Probing Extreme Environments**               | 2.1 What physical processes are at work close to neutron stars and black holes?  
2.2 What are the characteristics of relativistic jets, winds and explosions?  
2.3 How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time? |
| **3 Exploring Frontiers in Physics**             | 3.1 What is the nature of Dark Matter? How is it distributed?  
3.2 Are there quantum gravitational effects on photon propagation?  
3.3 Do Axion-like particles exist? |
Mapping of Science Themes to Key Science Projects

<table>
<thead>
<tr>
<th>Theme</th>
<th>Question</th>
<th>Dark Matter Programme</th>
<th>Galactic Centre Survey</th>
<th>Galactic Plane Survey</th>
<th>LMC Survey</th>
<th>Extragalactic Survey</th>
<th>Transients</th>
<th>Cosmic Ray PeVtevrons</th>
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<td>2.2 What are the characteristics of relativistic jets, winds and explosions?</td>
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<td>3.3 Do Axion-like particles exist?</td>
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</table>

(DM Programme and its observational components)
Key Science Projects KSPs

> KSP Concept
  - Programs of observations that map to CTA science themes
  - High scientific interest & broad interest to Consortium

> Motivation
  - Maximize scientific return of CTA with early “legacy” projects
  - Secure high-impact science for the Consortium
  - Justify significant fraction of guaranteed time for Consortium

> Outcome: observation planning, e.g.

<table>
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<tr>
<th>KSP/Programme</th>
<th>Required Dark Time (hours)</th>
<th>Main data products</th>
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<td>Extragalactic Survey</td>
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<td>-90 &lt; l &lt; 90, b &gt; 5</td>
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 Galactic plane survey

- Increase population by 3...9+
- CR PeVatrons, new binaries, ...
Galactic Physics with CTA

> Galactic plane survey
  - Increase population by 3...9+
  - CR PeVatrons, new binaries, ...

> Large Magellanic Cloud survey
Galactic Physics with CTA

- Galactic plane survey
  - Increase population by 3...9+
  - CR PeVatrons, new binaries, ...
- Large Magellanic Cloud survey
- PeVatrons
  - Extreme accelerators of PeV CRs
  - Young SNRs?
  - Simulation: +50 h each to confirm and characterize spectral shape
Galactic Physics with CTA

> Galactic plane survey
  - Increase population by 3...9+
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> Large Magellanic Cloud survey

> PeVatrons
  - Extreme accelerators of PeV CRs
  - Young SNRs?
  - Simulation: +50 h each to confirm and characterize spectral shape

> Example: study of FERMI pulsars
  ~50% detectable above 40 GeV
Extragalactic Physics with CTA

> AGN Survey
> Transients (e.g. GRBs)
> Extragalactic Survey
> Star forming Galaxies (shared)
> Cluster of Galaxies (shared)

> Observation strategy:
  - Long term monitoring
  - High quality spectra
  - AGN flare program
Extragalactic Physics with CTA

- AGN Survey
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- Cluster of Galaxies (shared)

Observation strategy:
- Long term monitoring
- High quality spectra
- AGN flare program

Example: divergent pointing
- FoV 4 times larger cf. normal pointing

3rd AGN FERMI catalog
FSRQs
BL Lacs

 Integral Flux Sensitivity (E-E_0) [C.U.]

- 0° – 7° Divergent Pointing
- 0° – 3.5° Normal Pointing

8 hours Divergent
2 hours Normal

~20%
Multiwavelength Program with CTA

> CTA covers 60 GeV → 200 TeV

80 MHz ← 17 orders of magnitude → 60 GeV

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<tr>
<th>N</th>
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<th>VLA</th>
<th>IRAM</th>
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<td>LSST</td>
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Many facilities, some very powerful new ones - FoV, versatility, and monitoring capabilities are crucial.

> Two-way interaction

- Straightforward for steady sources (observatories and/or VO-catalogs)
- For triggers, monitoring and alerts: provide triggers, facilitate monitoring programs (flexibility), react on MWL alerts (fast analysis)
From Physics Plans and Concepts to Requirements

- Good energy resolution of ~10% (lines, cutoffs)
- Large field of view of 8° (surveys, extended sources, flares)
- Improved angular resolution of few arc-min (source morphology)
- Energy coverage up to 300 TeV (Pevatrons)
- Energy coverage down to 20 GeV (AGN, cosmology)
- 10 x Sensitivity and collection area (nearly every topic)
- Rapid slewing (20 s) to catch flares
Large Arrays

North ~0.4 km\(^2\)  4 LST 15 MST
South ~4 km\(^2\)   4 LST 24 MST and 72 SST
Physics Program
Sensitivity Optimisation

> Study CTA capabilities for astrophysics & fundamental physics problems, galactic and extragalactic science, dark matter

> Study different array configurations and the impact of the site selection onto the physics cases of CTA
Physics Program
Sensitivity Optimisation

> Study CTA capabilities for astrophysics & fundamental physics problems, galactic and extragalactic science, dark matter

> Study different array configurations and the impact of the site selection onto the physics cases of CTA
CTA Performance

> Result of large-scale simulations (900 telescopes for layout optimisation, CTA-GRID) and analysis


> MC Prod3 started recently – more realistic estimation of CTA performance
CTA Site Selection

- CTA ground measurements
- Satellites
- Simulation/ extrapolation
CTA Site Selection

- CTA ground measurements
- Satellites
- Simulation/ extrapolation

- Clouds
- Wind, rain, hail, snow
- Earthquakes
- Aerosoles

- Sensitivity simulation
  - Altitude
  - Magnetic field
CTA Site Selection

- CTA ground measurements
- Satellites
- Simulation/ extrapolation

- Clouds
- Wind, rain, hail, snow
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- Aerosoles

- Sensitivity simulation
  - Altitude
  - Magnetic field

- Infrastructure
- Host country support
At a meeting in Munich, Germany, on 10 April, representatives from the 12 CTA partner countries inched closer to picking the sites. In the Southern Hemisphere, they narrowed the list down to two possibilities: Aar, in southern Namibia; and Cerro Armazones in Chile’s Atacama Desert. In the north, four sites remain in the running: two in the United States and one each in Mexico and Spain.

17 April 2014 | Vol 508 | Nature | 297
Detailed negotiations started in July 2015 with ESO (Chile) and Spain (La Palma)
Gamma-Ray Telescopes

- Drives
- Mirror
- Camera
- Structure
Gamma-Ray Telescopes

Drives

Mirror

Structure

Camera

Array control
Gamma-Ray Telescopes

Drives

Mirror

Camera

Array control

Structure

Safety Infrastructure

Logistics Commissioning
Gamma-Ray Telescopes

- Drives
- Mirror
- Camera
- Structure
- Array control
- Costs
- Schedule
- Safety
- Logistics
- Commissioning
- Infrastructure

S Schlenstedt | CTA | PRC Closed Session | Oct 22, 2015 | 21
Many Technical Systems

> Around 100 telescopes with six different designs on two sites
> Drive systems
> (A)spherical mirrors
> Cameras: PMTs and SiPM, readout electronics, trigger
> Pointing
> Calibration
> Array control
> Data management
> Observatory
From Prototypes to Production
CTA Project

- EU supported design phase 2010-2014
- Technical systems underwent internal reviews and external Preliminary Design Review late 2013
- A legal entity CTA Observatory was created 2014
  - Hosts the project office
  - Responsible for site negotiations
  - Prepares the CTA production phase
- Site selection procedure progressing towards decisions in 2015
- Critical Design Review July 2015
- Start of CTA construction planned for 2016
- Partial science operation in 2018
CTA Collaboration and Project Schedule and Funding

Schedule: site selection ➞ site development ➞ pre-production of telescopes 2016/2017 ➞ production of telescopes 2017…2020+

Current Cost estimate for base-line design: 300 M €

Different funding cycles in CTA member states

Expect big contributions from France, Germany, Italy, Japan, Spain; also Austria, Brazil, The Netherlands, Poland, Switzerland, UK, US…

German funding >51 M € – CTA on National roadmap

BMBF (grant proposal coordinated by DESY)

DESY/ Helmholtz

MPG – MPIK Heidelberg and MPP Munich

Universities Berlin, Dortmund, Erlangen, Hamburg, Heidelberg, Tübingen, Würzburg

CTA Consortium: 30 countries 180 institutes >1200 members
CTA Collaboration and Project Schedule and Funding

- Schedule: site selection → site development → pre-production of telescopes 2016/2017 → production of telescopes 2017...2020+
CTA Collaboration and Project Schedule and Funding

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  - DESY/ Helmholtz
  - MPG – MPIK Heidelberg and MPP Munich
  - Universities Berlin, Dortmund, Erlangen, Hamburg, Heidelberg, Tübingen, Würzburg
CTA in 2015

> Critical Design Review June 2015
- Delivery of Detailed Technical Design Reports for all WPs
- Plans for pre-production and production for 70-100 telescopes on Southern Array and 20 telescopes on Northern Array
- Towards CTA Cost Book and Schedule

> CTA Headquarters
- Expression of Interest by Germany (DESY, Zeuthen), Italy (INAF, Bologna), Brazil (Rio de Janeiro)
- Call for proposals early October 2015
- Deadline for applications Nov 22, 2015
- Decision spring 2016

> Site negotiations
**Medium-Sized Telescope Technical Design Report**

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**Array Control & Data Acquisition Technical Design Report**

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The Scientific and Technical Advisory Committee was presented with an impressive amount of written documentation – over four thousand pages of description of the science programme and the Technical Design Review (TDR) – and received nearly twelve hours of oral presentations. [...] The quality was unusually high [...]
CTA Involvement at DESY

> Medium-Sized Telescopes MST
  - Design and build structure, drive and safety system
  - Project Management responsibility

> Array Control ACTL
  - Work Package Array operation
  - Work Package On-site hardware
  - Timing System
  - Project Management responsibility, central activities

> Sensitivity Studies, e.g. CTA layout

> Data structures and pipelines

> High level software (ctools)
MST Activities
Recent examples

> Optimization of telescope
> Pointing and mirror alignment
> Understand MST mirrors
> Plan pre-production MSTs
DESY ACTL Group

- Some specific activities of the team:
  - Project leadership and management with system architecture
  - Design and implementation of the central control and operator GUI elements
  - Onsite computing and network instrumentation design
  - MST slow control: telescope drive system, image acquisition, monitoring
  - Inter-telescope time synchronization

- Work with external software architecture consultants and DESY IPP
Cherenkov Telescope Array

- A unique and versatile instrument for astronomy and astro-particle physics
- Experience of H.E.S.S., MAGIC and VERITAS
- First observatory in TeV band on both hemispheres – open for a world-wide community

> Preparation
  - Design, prototypes, cost-model
  - Site selection and development
  - Establish project structure
  - Pre-production and production and deployment

> Establish observatory

> Prepare science operation